# Animal performance and fatty acid composition of lambs fed with different vegetable oils

T. Manso [a,*], R. Bodas [b], T. Castro [c], V. Jimeno [d], A.R. Mantecon [b]

[a] ETS Ingenierías Agrarias, Universidad de Valladolid, 34004 Palencia, Spain
[b] Instituto de Ganadería de Montaña (CSIC-ULE), 24346 Grulleros, León, Spain
[c] Dept. Producción Animal, Univ. Complutense de Madrid, 28040 Madrid, Spain
[d] Dept. Producción Animal, Univ. Politécnica de Madrid, 28040 Madrid, Spain

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ABSTRACT

Twenty-seven lambs were used to investigate the effects of the inclusion of 4% hydrogenated palm oil (HPO) or sunflower oil (SFO) in the concentrate on animal performance, carcass and meat quality and fat characteristics and fatty acid composition. Animals (16.2 ± 0.27 kg initial weight) were fed concentrate (Control, HPO or SFO) and barley straw ad libitum and slaughtered at 25 kg. SFO lambs tended to eat less concentrate than HPO animals ($P < 0.10$). Neither HPO nor SFO affected any of the carcass characteristics studied, meat pH and meat and fat colour ($P > 0.05$). SFO decreased proportions of C16:0, C18:1 *cis-11* and C18:3 ($P < 0.05$) and increased C18:1 *trans* ($P < 0.001$) and C18:2/C18:3 ratio ($P < 0.05$). Atherogenicity index was lower ($P < 0.05$) when SFO was included in the concentrate. HPO did not affected and SFO improved fatty acid composition of fattening lambs without affecting animal performance.

## 1. Introduction

In the Mediterranean area, intensively reared lambs are usually fed with barley straw and concentrate ad libitum in order to achieve great growth rates. Over the last decade, fat supplementation became a common practice to increase the energy density of the diet for ruminants (Bauman, Corl, & Peterson, 2003), palm oil supplements being the most used, since they do not have the negative effects on rumen fermentation as unsaturated oils (Jenkins, 1993). However, the type of fat in the ration is known to affect the composition of body fat (Bas & Morand Fehr, 2000).

Lamb fat is characterized by a high saturated fatty acid (SFA) content, and a low polyunsaturated fatty acid (PUFA) content (Enser, Hallett, Hewitt, Fursey, & Wood, 1996), due to the biohydrogenation of unsaturated fatty acids by rumen microflora (Doreau & Ferlay, 1994). Nevertheless, meat from ruminant animals (Pariza & Ha, 1990) is within the primary sources of conjugated linoleic acid (CLAs) for humans, which has been associated with a wide range of positive health benefits. One of the options of enhancing the beneficial effects of animal products is through diet manipulation, such as the use of finishing diets supplemented with sunflower oil with high purities of linoleic or oleic fatty acids to improve the concentration of CLAs and thus their health benefits (Kott et al., 2003). On the other hand, the use of such oil has been proposed as an alternative to increase the content of PUFA in lamb tissues (Yu et al., 2008). Studies appear to focus on a higher ruminal C18:1 *trans-11* production to enhance endogenous formation of CLA *cis-9*, *trans-11* both in beef and lamb and to investigate if production of the precursor, or the activity of the Δ9-desaturase, is the limiting factor for achieving a higher tissue CLA deposition (Raes, De Smet, & Demeyer, 2004). However, although several adverse effects of *trans*-fatty acids on human health have been reported, C18:1 *trans-11* (typically the major *trans*-fatty acid in ruminant fat) can serve as a precursor for endogenous CLA *cis-9*, *trans-11* synthesis in human tissues (Ryhänen et al., 2005). Nevertheless, there are no studies comparing the effects of the inclusion of fats with different level of saturation on lambs performance and fatty acid composition.

The present work was conducted to study the effects of 4% hydrogenated palm oil (HPO) or sunflower oil (SFO) supplementation in the concentrate for fattening lambs on feed intake, animal performance, carcass and meat characteristics and meat and subcutaneous fatty acid composition.

## 2. Materials and methods

### 2.1. Animals

Twenty-seven male Merino lambs (initial age 8–9 weeks) were allocated by stratified randomization on the basis of live body

* Corresponding author. Address: Área de Producción Animal, E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Avda. Madrid, s/n, 34004 Palencia, Spain. Tel.: +34 979 10 8367; fax: +34 979 10 8302.
*E-mail address:* tmanso@agro.uva.es (T. Manso).

weight (LBW, 16.2 ± 0.27 kg) into three equal groups to study the effects of the inclusion of 4% hydrogenated palm oil (HPO) and 4% sunflower oil (SFO) in the concentrate offered during the fattening period.

The lambs were kept with their mothers until weaning, with free access to a commercial starter concentrate, barley straw and alfalfa hay until the commencement of the trial. They were dewormed by dosing with Ivomec (Merial Labs., Spain) and vaccinated against enterotoxaemia (Miloxan, Merial Labs., Spain).

Animals were housed individually and animal handling followed the recommendations of European Council Directive 86/609/EEC for protection of animals used for experimental and other scientific purposes.

### 2.2. Diets

After 5 days of adaptation to the control diet (barley straw and concentrate feed without oil added), lambs were fed barley straw and the corresponding experimental concentrate feed ad libitum. The ingredients and chemical composition of the concentrates are given in Table 1. Hydrogenated palm oil and sunflower oil were added to and mixed completely with the concentrate before feeding each lamb.

### 2.3. Experimental procedure

Concentrate and forage (in long form) were supplied in separate feeding troughs and fresh drinking water was always available. The amount of feed offered was adjusted daily on the basis of the previous day intake, allowing refusals of 20%. The amounts of feeds offered and of refusals were weighed daily, and samples were collected for subsequent analyses.

Animals were weighed before morning feeding twice a week to about 24 kg LBW and then every day until the slaughter LBW (25 kg).

**Table 1**
Ingredients and chemical composition of experimental concentrates (g/kg).

| | Control | HPO | SFO |
|---|---|---|---|
| Barley grain | 520 | 500 | 500 |
| Corn grain | 153 | 147 | 147 |
| Soybean meal | 214 | 205 | 205 |
| Sunflower meal | 29 | 28 | 28 |
| Hydrogenated vegetable fat[a] | – | 40 | – |
| Sunflower oil[b] | – | – | 40 |
| Molasses | 42 | 40 | 40 |
| Sodium bicarbonate | 10 | 10 | 10 |
| Vitamin mineral premix[c] | 31 | 30 | 30 |
| Dry matter | 887 | 888 | 894 |
| Ash | 63 | 61 | 61 |
| Neutral detergent fibre | 127 | 123 | 120 |
| Crude protein | 164 | 157 | 157 |
| Ether extract | 16 | 55 | 54 |
| *Fatty acids (% of total fatty acids)* | | | |
| C16:0 | 16.7 | 50.6 | 8.8 |
| C18:0 | 1.5 | 1.9 | 3.4 |
| C18:1 | 20.0 | 12.6 | 26.7 |
| C18:2 | 57.1 | 15.3 | 60.0 |
| C18:3 | 4.5 | 1.2 | 1.2 |

[a] Hidrogenated vegetable fat (NUCLEOVIT-99®, Lechavit S.A., León, Spain). Analysis: 990 g ether extract/kg of DM. Fatty acid composition (g/kg fatty acids): C14:0, 12; C16:0, 625; C18:0, 257, C18:1, 98.

[b] Sunflower oil (C.C. Carrefour S.A., Spain). Analysis: 990 g ether extract/kg of DM. Fatty acid composition (g/kg fatty acids): C16:0, 60; C18:0, 40; C18:1, 288; C18:2, 605.

[c] Vitamin mineral premix (NUTEMIX®, NUTEGA, Madrid, Spain).

#### 2.3.1. Slaughter and carcass measurements

When an animal reached the intended LBW (approximately 25 kg), feed and water were withdrawn, and after 1 h the lamb was weighed again, stunned, bled, skinned and eviscerated.

Dressed carcass and non-carcass components (as defined by Colomer-Rocher, Delfa, & Sierra, 1988) were obtained from the whole body of each lamb and weighed separately. Carcass was chilled at 4 °C for 24 h and then weighed again, so that chilling losses were calculated as the difference between hot (HCW) and cold carcass weight (CCW) expressed as a proportion of the initial HCW. Killing-out percentage was calculated as CCW expressed as percent of slaughter body weight.

Thoracic wall thickness (mm), subcutaneous fat thickness (mm), fatness score and consistency of fat were determined as described by Colomer-Rocher et al. (1988).

The left side of each carcass was jointed into commercials cuts (shoulder, breast-flank, leg, scrag end, best end, loin-rib and tail) according to Colomer-Rocher et al. (1988). Each cut was weighed to assess its proportion in the carcass. Thereafter, the shoulder was dissected into bone, lean and fat depots according to the procedure of Fisher and De Boer (1994) to determine tissular composition of the carcass.

#### 2.3.2. Meat measurements

At 24-h post-mortem, loin-rib joint (from 6th rib-onwards) was cut at the level of 13th rib, and pH and colour were measured at the 6th rib site. pH was also measured in *m. semimembranosus* and colour was also measured in *m. rectus abdominis* and dorsal subcutaneous fat. A Metrohm® pHmeter (Metrohm, Switzerland), equipped with penetrating electrode and temperature probe was used for pH determination. Colour measurements were performed according to the $L^*a^*b^*$ system (Commission International de l'Eclairage, 1976) using a Minolta CM-2002 chromameter (Konica-Minolta Sensing, Japan). Fat colour was evaluated in subcutaneous dorsal fat.

A sample of *m. longissimus thoracis* was taken to determine water holding capacity as described by Grau and Ham (1953) and modified by Sañudo, Sierra, López, and Forcada (1986), and samples of this muscle and subcutaneous fat (fat sample from a point situated 4 cm from last rib and 4 cm from medium line) were taken and frozen at −30 °C for fatty acid composition determination.

The chemical composition of the meat was determined on *m. longissimus lumborum* samples, which were analyzed for dry matter (AOAC official method 950.46), ash (AOAC official method 920.153), crude protein (AOAC official method 981.10) and fat (AOAC official method 960.39).

In situ transesterification of fatty acids were performed following the method described by Carrapiso, Timón, Petrón, Tejeda, and García (2000), using 300 mg of freeze dried and minced *m. longissimus lumborum*. Anhydrous HCl/methanol was used for the methylation of the fatty acids and tridecanoic acid (C13:0) was used as internal standard (4 mg/ml). Methyl esters of fatty acids were quantified by GC (HP 5890 GC, Hewlett–Packard, USA) using a capillary column (HP 88, 100 m × 0.25 mm, Agilent Technologies, USA). The injector and detector temperatures were of 200 and 300 °C, respectively, and the helium flow ratio was 1 ml/min. An automatic split/splitless injector as used with a ratio 30:1 split and pressure of 16 psi. After injection (1 μl), the column temperature was held at 50 °C for 1 min and then increased to 180 °C at 10 °C/min. The temperature was kept at 180 °C for 25 min, followed by an increase of 2 °C/min to 220 °C and, finally, held at 260 °C for 5 min.

The identification of peaks was made by comparison of retention times with the ones obtained for fatty acid methyl ester (FAME) standard mixtures acquired from Un-Check-Prep Inc. (Elysian, MN, USA) and from Supelco Inc. (Bellefonte, PA, USA).

Additional standards of individual CLA isomers (C18:2 *cis-9, trans-11*, C18:2 *trans-10, cis-12*) were purchased from Matreya Inc. (Pleasant Gap, PA, USA). Atherogenicity index was calculated as described by Ulbricht and Southgate (1991):

$$(C12:0 + 4 \times C14:0 + C16:0)/(MUFA + PUFA)$$

*2.3.3. Statistical analysis*

Average daily weight gain (ADG) was estimated as the regression coefficient (slope) of LBW against time using the REG procedure of SAS package (SAS Inst. Inc., 1999). Data were subjected to analysis of variance using the GLM procedure of SAS package (SAS, 1999). The LSD test was used to assess the significance between treatment means where the effect was significant ($P < 0.05$).

## 3. Results

Mean values of feed intake, average daily gain, feed to gain ratio and days to reach 25 kg are shown in Table 2. SFO lambs tended to eat less concentrate and total dry matter than HPO animals ($P < 0.10$), whereas these showed a tendency to lower barley straw intake than Control lambs ($P < 0.10$). On the other hand, average daily gain and feed to gain ratio were not affected by HPO or SFO diets ($P > 0.05$) compared to control diet.

There were no statistically significant effects of HPO or SFO as compared to control diet on hot and cold carcass weight, chilling losses, carcass conformation, fatness score and consistency, internal fat depots weight and thickness of thoracic wall and subcutaneous fat ($P > 0.10$) (Table 3).

**Table 2**
Feed dry matter intake, average daily gain, feed to gain ratio and days to reach 25 kg LBW.

| | Group | | | | |
|---|---|---|---|---|---|
| | Control | HPO | SFO | RSD[a] | *P*-value |
| *Dry matter intake (g animal$^{-1}$ day$^{-1}$)* | | | | | |
| Concentrate | 910 | 973 | 852 | 104.0 | 0.077 |
| Barley straw | 53 | 27 | 46 | 23.8 | 0.074 |
| Total | 963 | 999 | 898 | 98.7 | 0.124 |
| Average daily gain (g animal$^{-1}$ day$^{-1}$) | 243 | 273 | 255 | 40.1 | 0.284 |
| Feed: gain | 4.02 | 3.73 | 3.63 | 0.693 | 0.476 |
| Days to reach 25 kg | 32.2 | 30.0 | 32.4 | 5.71 | 0.618 |

[a] RSD: residual standard deviation.

**Table 3**
Carcass characteristics (1).

| | Groups | | | | |
|---|---|---|---|---|---|
| | Control | HPO | SFO | RSD[a] | *P*-value |
| Hot carcass (kg) | 12.7 | 12.4 | 12.4 | 0.49 | 0.497 |
| Cold carcass (kg) | 12.3 | 12.1 | 12.0 | 0.48 | 0.453 |
| Chilling losses (%) | 2.79 | 2.89 | 2.94 | 0.264 | 0.536 |
| Killing-out percentage | 48.6 | 47.5 | 47.3 | 1.70 | 0.236 |
| Carcass conformation[b] | 5.11 | 5.50 | 5.71 | 1.420 | 0.691 |
| Fatness score[c] | 4.88 | 5.13 | 5.14 | 1.277 | 0.899 |
| Fat consistency[d] | 4.75 | 4.63 | 5.00 | 0.932 | 0.737 |
| Fat internal depots (g) | | | | | |
| Omental | 275 | 262 | 300 | 82.0 | 0.668 |
| Mesenteric | 184 | 187 | 194 | 31.7 | 0.817 |
| Kidney knob and channel fat | 226 | 244 | 247 | 62.8 | 0.768 |

[a] RSD: residual standard deviation.
[b] Carcass conformation scale: from 0 (poor) to 5 (excellent).
[c] Fatness score scale: from 0 (slim) to 4 (very fat).
[d] Fat consistency scale: from 0 (oily) to 3 (firm).

**Table 4**
Carcass characteristics (2).

| | Groups | | | | |
|---|---|---|---|---|---|
| | Control | HPO | SFO | RSD[a] | *P*-value |
| *Thickness (mm)* | | | | | |
| Thoracic wall | 4.55 | 4.49 | 5.16 | 0.806 | 0.234 |
| Subcutaneous fat | 3.06 | 3.10 | 3.70 | 1.212 | 0.531 |
| *Commercial cuts (%)* | | | | | |
| Shoulder | 20.5 | 20.1 | 20.5 | 1.02 | 0.625 |
| Breast-flank | 12.6 | 12.1 | 12.8 | 1.14 | 0.491 |
| Leg | 33.5 | 33.9 | 33.1 | 1.27 | 0.495 |
| Scrag end | 9.3 | 9.2 | 9.5 | 0.82 | 0.720 |
| Loin-rib | 16.8 | 17.4 | 17.0 | 1.77 | 0.807 |
| Best end | 6.0 | 6.1 | 5.8 | 0.69 | 0.681 |
| Tail | 1.2 | 1.3 | 1.3 | 0.21 | 0.892 |
| *Tissular composition (%)* | | | | | |
| Muscle | 60.3 | 61.2 | 60.8 | 2.76 | 0.783 |
| Intermuscular fat | 8.0 | 7.8 | 8.5 | 1.63 | 0.711 |
| Subcutaneous fat | 10.5 | 10.0 | 10.6 | 2.93 | 0.905 |
| Bone | 18.6 | 18.5 | 17.7 | 1.45 | 0.507 |
| Others | 2.7 | 2.5 | 2.3 | 0.47 | 0.319 |

[a] RSD: residual standard deviation.

**Table 5**
Meat pH, colour, water holding capacity and chemical composition, and fat characteristics.

| | Groups | | | | |
|---|---|---|---|---|---|
| | Control | HPO | SFO | RSD[a] | *P*-value |
| *Meat pH 24-h post-slaughter* | | | | | |
| *L. dorsi* | 5.83 | 5.84 | 5.81 | 0.086 | 0.833 |
| Semimembranosus | 5.79 | 5.79 | 5.75 | 0.071 | 0.397 |
| *R. abdominis* colour | | | | | |
| $L^*$ | 49.3 | 48.3 | 49.4 | 2.22 | 0.527 |
| $a^*$ | 9.07 | 9.44 | 8.78 | 0.974 | 0.434 |
| $b^*$ | 2.50 | 2.62 | 2.17 | 1.641 | 0.862 |
| *L. dorsi* | | | | | |
| Colour | | | | | |
| $L^*$ | 38.7 | 40.2 | 39.9 | 2.71 | 0.510 |
| $a^*$ | 11.5 | 10.9 | 10.6 | 1.16 | 0.278 |
| $b^*$ | 3.38 | 3.26 | 3.04 | 1.674 | 0.923 |
| Water holding capacity (%) | 17.6 | 17.9 | 17.7 | 3.49 | 0.987 |
| *Chemical composition* | | | | | |
| Dry matter (%) | 23.5 | 22.2 | 24.8 | 1.56 | 0.184 |
| Crude protein (%DM) | 78.0 | 79.4 | 77.7 | 3.47 | 0.700 |
| Ether extract (% DM) | 11.6 | 11.1 | 12.9 | 2.80 | 0.905 |
| Ash (% DM) | 7.6 | 7.6 | 6.6 | 1.20 | 0.238 |
| *Fat colour* | | | | | |
| $L^*$ | 66.4 | 67.6 | 68.1 | 2.77 | 0.445 |
| $a^*$ | 3.89 | 3.59 | 3.89 | 0.857 | 0.730 |
| $b^*$ | 10.24 | 9.55 | 10.19 | 1.346 | 0.526 |

[a] RSD: residual standard deviation.

Neither HPO nor SFO caused changes in commercial cuts percentage or tissular composition ($P > 0.10$) when compared to control group, as can be seen in Table 4.

Meat pH, colour and chemical composition, as well as fat colour parameters are shown in Table 5, and none of them resulted affected by the oils studied ($P > 0.10$).

Intramuscular fatty acid composition is recorded in Table 6. Whereas HPO did not cause significant changes as compared to control group, the addition of SFO to the concentrate decreased C16:0 ($P < 0.05$). C18:1 *trans* proportion was statistically greater ($P < 0.01$) and C18:1 *cis-11* lower ($P < 0.05$) for SFO lambs when compared to either control or HPO animals. Linolenic acid (C18:3) proportion lowered when 4% SFO was included in the concentrate, which led to a greater C18:2/C18:3 ratio ($P < 0.05$). Saturated (SFA), monounsaturated (MUFA) and long-chain

**Table 6**
Intramuscular fatty acid composition (% of identified fatty acids).

| | Groups | | | | |
|---|---|---|---|---|---|
| | Control | HPO | SFO | RSD[w] | *P*-value |
| C14:0 | 2.64 | 2.37 | 2.31 | 0.423 | 0.181 |
| C16:0 | 23.75[a] | 23.67[a] | 22.15[b] | 1.305 | 0.026 |
| C16:1 | 1.41 | 1.61 | 1.46 | 0.501 | 0.632 |
| C18:0 | 16.39 | 16.23 | 17.32 | 1.500 | 0.277 |
| C18:1 *trans* | 3.54[b] | 4.38[b] | 6.30[a] | 1.437 | 0.001 |
| C18:1 *cis-9* | 36.97 | 36.94 | 35.20 | 2.661 | 0.295 |
| C18:1 *cis-11* | 1.80[a] | 1.91[a] | 1.54[b] | 0.240 | 0.010 |
| Total C18:1 | 42.31 | 43.23 | 43.04 | 2.684 | 0.701 |
| C18:2 *cis-9, cis-12* | 5.99 | 5.87 | 5.75 | 1.722 | 0.955 |
| C18:2 *cis-9, trans-11* | 0.35 | 0.33 | 0.39 | 0.097 | 0.460 |
| C18:2 *trans-10, cis-12* | 0.06 | 0.05 | 0.06 | 0.030 | 0.802 |
| C18:3 | 0.44[a] | 0.40[a] | 0.30[b] | 0.099 | 0.019 |
| C20:0 | 0.02 | 0.05 | 0.06 | 0.040 | 0.084 |
| C20:4 *n-6* | 4.04 | 3.97 | 3.74 | 2.127 | 0.965 |
| C20:5 *n-3* | 0.51 | 0.58 | 0.63 | 0.336 | 0.792 |
| C22:5 *n-3* | 0.80 | 0.96 | 0.93 | 0.500 | 0.813 |
| C22:6 *n-3* | 0.42 | 0.35 | 0.47 | 0.212 | 0.638 |
| SFA[x] | 42.97 | 42.45 | 41.95 | 1.917 | 0.510 |
| MUFA[x] | 43.72 | 44.84 | 44.50 | 2.859 | 0.645 |
| PUFA[x] | 13.30 | 12.70 | 13.53 | 3.953 | 0.896 |
| Total CLA[y] | 0.41 | 0.38 | 0.45 | 0.097 | 0.368 |
| SFA/(MUFA + PUFA) | 0.76 | 0.74 | 0.73 | 0.059 | 0.524 |
| C18:2/C18:3 | 14.9[b] | 16.3[b] | 22.7[a] | 4.99 | 0.006 |
| Atherogenicity index[z] | 0.61 | 0.58 | 0.55 | 0.061 | 0.105 |

[a,b]Means within rows with different superscript differ significantly ($P < 0.05$).
[w] RSD: residual standard deviation.
[x] SFA = C14:0 + C16:0 + C18:0 + C20:0; MUFA = C16:1 + C18:1; PUFA = C18:2 *cis-9, cis-12* + C18:2 *cis-9, trans-11* + C18:2 *trans-10, cis-12* C20:4 *n-6* + C20:5 *n-3* + C22:5 *n-3* + C22:6 *n-3*.
[y] Total CLA = C18:2 *cis-9, trans-11* + C18:2 *trans-10, cis-12*.
[z] Ulbricht and Southgate (1991).

**Table 7**
Subcutaneous fatty acid composition (% of identified fatty acids).

| | Groups | | | | |
|---|---|---|---|---|---|
| | Control | HPO | SFO | RSD[w] | *P*-value |
| C14:0 | 3.35 | 3.03 | 2.88 | 0.633 | 0.247 |
| C16:0 | 24.54[a] | 25.34[a] | 21.59[b] | 1.855 | 0.001 |
| C16:1 | 1.62[a] | 1.67[a] | 1.18[b] | 0.376 | 0.020 |
| C18:0 | 20.01 | 18.29 | 21.07 | 3.637 | 0.273 |
| C18:1 *trans* | 6.61[b] | 7.73[b] | 12.51[a] | 2.588 | <0.001 |
| C18:1 *cis-9* | 37.43 | 37.32 | 34.55 | 4.460 | 0.322 |
| C18:1 *cis-11* | 1.56 | 1.59 | 1.41 | 0.173 | 0.083 |
| Total C18:1 | 45.59 | 46.64 | 48.47 | 3.351 | 0.189 |
| C18:2 *cis-9, cis-12* | 3.20 | 3.34 | 3.10 | 1.007 | 0.873 |
| C18:2 *cis-9, trans-11* | 0.43 | 0.49 | 0.56 | 0.246 | 0.510 |
| C18:2 *trans-10, cis-12* | 0.03[b] | 0.05[b] | 0.10[a] | 0.030 | <0.001 |
| C18:3 | 0.33[a] | 0.32[a] | 0.20[b] | 0.086 | 0.005 |
| C20:0 | 0.05 | 0.09 | 0.11 | 0.059 | 0.124 |
| C20:4 *n-6* | 0.04 | 0.04 | 0.01 | 0.030 | 0.105 |
| C20:5 *n-3* | 0.19 | 0.20 | 0.15 | 0.062 | 0.289 |
| C22:5 *n-3* | 0.16 | 0.17 | 0.16 | 0.039 | 0.783 |
| C22:6 *n-3* | 0.07 | 0.06 | 0.06 | 0.037 | 0.860 |
| SFA[x] | 48.15 | 46.90 | 45.78 | 3.667 | 0.373 |
| MUFA[x] | 47.22 | 48.30 | 49.65 | 3.613 | 0.350 |
| PUFA[x] | 4.63 | 4.80 | 4.57 | 1.088 | 0.896 |
| Total CLA[y] | 0.46 | 0.53 | 0.67 | 0.240 | 0.199 |
| SFA/(MUFA + PUFA) | 0.94 | 0.89 | 0.85 | 0.130 | 0.319 |
| C18:2/C18:3 | 12.2[b] | 13.0[b] | 20.7[a] | 4.14 | <0.001 |
| Atherogenicity index[z] | 0.74[a] | 0.71[ab] | 0.62[b] | 0.102 | 0.048 |

[a,b]Means within rows with different superscript differ significantly ($P < 0.05$).
[w] RSD: residual standard deviation.
[x] SFA = C14:0 + C16:0 + C18:0 + C20:0; MUFA = C16:1 + C18:1; PUFA = C18:2 *cis-9, cis-12* + C18:2 *cis-9, trans-11* + C18:2 *trans-10, cis-12* C20:4 *n-6* + C20:5 *n-3* + C22:5 *n-3* + C22:6 *n-3*.
[y] Total CLA = C18:2 *cis-9, trans-11* + C18:2 *trans-10, cis-12*.
[z] Ulbricht and Southgate (1991).

polyunsaturated (PUFA) fatty acids as well as atherogenicity index were not affected by either HPO or SFO.

Fatty acid composition of subcutaneous fat is shown in Table 7. SFO caused significant decreases in the proportion of C16:0 and C16:1 ($P < 0.05$) as compared to HPO and control lambs. C18:1 *trans* proportion increased significantly in SFO lambs ($P < 0.001$), whereas C18:1 *cis-11* tended to decrease when SFO animals were compared to HPO lambs ($P < 0.10$). C18:2 *trans-10, cis-12* proportion increased in SFO lambs ($P < 0.001$). C18:3 proportion decreased significantly when SFO was added to the concentrate ($P < 0.01$), C18:2 to C18:3 ratio increasing for SFO lambs ($P < 0.001$). SFO significantly decreased the atherogenicity index when compared to control diet ($P < 0.05$). However, long-chain PUFA were not affected by treatments studied ($P > 0.1$).

## 4. Discussion

The effects of adding fat to the diets for ruminants depend not only on the type of fat (Doreau & Chilliard, 1997) but also on the amount added. Likewise, it has been proposed that the digestive processes in the hindgut compensated for the possible reduction in digestion in the rumen resulting in a limited effect on whole tract digestion (Sutton, Knight, McAllan, & Smith, 1983). In our experiment, animals receiving fat in the diet did not show reduced total dry matter intake, even though SFO group ate less concentrate than HPO lambs. Nevertheless, animal performance was not affected, since no differences were observed in growth rate and feed to gain ratio. Haddad and Younis (2004) and Bessa, Portugal, Mendes, and Santos-Silva (2005) recorded reduced feed intake when ruminally protected fat (5%) and soybean oil (10%), were included in the ration for lambs. Despite these changes, average daily gain was not modified in any case. Notwithstanding, Dutta, Agnihotri, and Rao (2008) suggested that including palm oil in the diet could improve average daily gain and animal performance. It should be pointed out that their trial lasted double time than current experiment, their animals being also heavier than ours at the beginning or the experiment.

None of the carcass characteristics studied in this experiment were affected by the addition of either HPO or SFO to the concentrate. Previous works have shown that adding fats to the diet for fattening lambs does not cause modifications in animal performance or carcass characteristics (Haddad & Younis, 2004). Our results agree with Castro, Manso, Mantecón, Guirao, and Jimeno (2005) who found no differences for these parameters when lambs received up to 6% of supplementing fat. Likewise, Kott et al. (2003) did not observe differences in kidney knob and channel fat weight in an experiment carried out with lambs, whose diet was supplemented with 6% sunflower oil. On the other hand some studies have shown changes related to fat deposition. Thus, Bessa et al. (2005) observed greater proportion of intramuscular fat and less proportion of muscle when lambs were fed with 10% soybean oil. Moreover, Brandt and Anderson (1990) and Zinn (1992) suggested that supplementing ruminant rations with oil would increase carcass fatness. Nevertheless, the latter studies were performed in cattle and lasted more than our experiment, and the level of fat included was also greater (6% vs. 4%).

The lack of effects on commercial cuts percentage and tissular composition is according with the lacking differences in growth rate and carcass fatness, the mean values being within the range found in the bibliography for lambs reared under similar systems (Cano-Expósito et al., 2006; Rodríguez et al., 2008). It must be pointed out that changes in these parameters are usually related to changes in growth rates, age and maturity (Huidobro & Cañeque, 1994).

Regarding meat characteristics, no changes were found attributable to addition and type of oil added. Some authors have found changes in pH decline, relating them to the diet, but these relationships are based on the carcass fatness and chilling rate (Aahlus, Janz, Tong, Jones, & Robertson, 2001). As for meat colour, changes were not expected, since they are usually associated to differences in fat content, carcass fatness or ultimate pH (Priolo, Micol, & Agabriel, 2001), and no differences were observed for these parameters. Likewise, no differences were observed in fat colour. Changes in it are linked to differences in pigments deposition or fatty acid composition, the latter being associated to lipid oxidation processes, which are still not apparent for 24 h after slaughter (Wood et al., 2004). Nevertheless, in our study, modifications observed in fatty acid composition, did not lead to great changes in PUFA or MUFA proportions, which may have bigger influence in lipid oxidation than only rumenic or vaccenic acid.

Values of fatty acid composition agree with those found in the bibliography (Castro et al., 2005), the most abundant fatty acid being oleic (C18:1 *cis-9*), followed by palmitic (C16:0) and stearic (C18:0).

Regarding the effects of HPO in fatty acid composition, these are almost negligible in the current experiment when compared to control group. In this sense, previous works have shown that the effects of palm oil supplements on fatty acid composition are more likely to be evident in internal depots such as omental and mesenteric fat (Castro et al., 2005). Moreover, HPO group had to be included in the experimental design in order to clarify whether the effects observed were due to the addition of fat, to the type of fat added or both.

In the current study, the addition of SFO to the concentrate caused a significant decrease in the proportion of palmitic acid (C16:0) in both intramuscular and subcutaneous fat, which is probably due to its lower proportion in the SFO than in the other two diets. This agrees with previous works suggesting that the content of this fatty acid reflect its dietary concentration (Cooper et al., 2004; Scollan et al., 2001).

High-concentrate diets are associated with high levels of C18:1 *trans-10* (Bessa et al., 2005). Although in the current experiment the chromatographic peaks corresponding to *trans-10* and *trans-11* C18:1 isomers could not be differentiated, the peak has been interpreted as C18:1 *trans*, according to Bessa et al. (2005). It has been suggested that this fatty acid could be formed by reduction of *trans-10* CLA or by isomerization of oleic acid (Griinari & Bauman, 1999).

Sunflower oil, added at a rate of 6%, has been reported to increase CLA content in the intramuscular fat of lambs (Mir, Rushfeldt, Mir, Paterson, & Weselake, 2000). In the current study, CLA *trans-10, cis-12* as well as C18:1 *trans* increased in subcutaneous fat of animals receiving SFO diet. However, none of both changed in response to HPO or SFO in intramuscular fat. In this sense, previous works have shown greater changes in subcutaneous than in intramuscular fat (Castro et al., 2005; Lourenço, Van Ranst, De Smet, Raes, & Fievez, 2007). This lack of significant changes in intramuscular fat could be due to the fact that during the finishing period subcutaneous adipose tissue increases at a greater rate than other adipose depots, such as intramuscular (Demeyer & Doreau, 1999). On the other hand, subcutaneous fat seems to be more responsive to changes in the dietary fatty acid supply or changes in rumen metabolism than intramuscular fat (Demirel et al., 2004; Wachira et al., 2002).

Similarly to the results observed in the current experiment using SFO, in a trial with cattle, Beaulieu, Drackley, and Merchen (2002) reported an increase in CLA *trans-10, cis-12* when supplementing high-concentrate finishing diets with soybean oil, but not an increase in CLA *cis-9, trans-11*. Therefore, as they did, it can be suggested that supplementing high-concentrate diets with an oil source of linoleic acid is not an efficacious method for increasing the proportion of the latter fatty acid. Indeed, in a study carried out with lambs, Bessa et al. (2005) observed an increase in CLA *trans-10, cis-12* and C18:1 *trans-10*, while CLA *cis-9, trans-11* and C18:1 *trans-11* were not statistically affected in response to soybean oil supplementation to high-concentrate diets.

On the other hand, in response to the addition of other oils such as soybean oil, Bessa et al. (2005) reported an increase in C18:3 proportions. As in the current experiment SFO instead of soybean oil was used, which is known to have smaller concentrations of C18:3 than the latter, our results show a decrease in C18:3 in response to SFO, as Mir et al. (2000) reported previously. Although these authors did not provide a suitable explanation for this fact, it could be related to biohydrogenation process within the rumen, which is extensive and may be enhanced when animals receive a high unsaturated lipid supplements (Wachira et al., 2001).

Fat with high atherogenicity index value is assumed to be more detrimental to the human health (Ulbricht & Southgate, 1991). Conversely, some unsaturated fatty acids have a protective effect against the risk of cardiovascular disease (Williams, 2000). In the present study, a significant decrease in the atherogenicity index was found in response to SFO supplementation in subcutaneous fat. Intramuscular fat showed only a tendency to have lower atherogenicity index, which could probably be related to the numeric changes in saturated and monounsaturated fatty acids, which did not reach the required significance level to be statistically different.

It is not yet clear whether the effects on health of *trans*-fatty acids from ruminant products are opposite situation to the possible adverse of *trans*-fatty acid isomers from partially hydrogenated plant oils. However, although C18:1 *trans-11* seems to play a more important role than the *trans-10* isomer in modulating plasma lipid and lipoprotein metabolism (Roy et al., 2007), CLA *cis-9, trans-11* and CLA *trans-10, cis-12* have potential beneficial effects for human health, since both have be found to exert significant but different biological effects (Park, 2008).

It can be concluded that whereas 4% HPO does not have great effects, the inclusion of 4% SFO in the concentrate for young fattening lambs improves intramuscular and subcutaneous fatty acid composition without affecting feed intake, animal performance and carcass and meat characteristics.

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